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No. 10

Instrumentation

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(Columbia University)

Palisades, New York

INSTRUMENTATION

Technical Report No. 10

by

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ABSTRACT

A discussion of the broad purposes and general accomplishments of an instrumentation program to provide equipment for a seismological observatory and a field seismic recording apparatus is presented. The individual projects and instruments are described. A summary of present and future instrumentation projects is given.

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INTRODUCTION

This report is a summary of the instrumentation program carried out under Contract W-28-099 ac-396 during the period February 1948 - December 1950. This introduction will serve to outline the broad purposes of the various instrumentation projects undertaken and to describe the utilization of the instruments. The main body of the report includes a detailed description of the individual projects. A summary of present and future instrumentation concludes the report.

The instrumentation program was directed along two lines:

1. To provide equipment for a seismological observatory for the study of microseisms, earthquakes, and wave propagation in general.
2. To provide equipment for seismological field work utilizing routine quarry blasts and explosions set off at sea as sources of elastic waves.

In order to begin both aspects of the instrumentation program as quickly as possible, the first project undertaken was the design and construction of a seismometer suitable for both observatory and field recording of elastic waves. The seismometer is described in Section I. Shortly after the first six vertical components were built, a horizontal component seismometer for field use was designed and constructed (Section I).

Secondly, concurrently with the construction of the vertical component seismometers, amplifiers and recording equipment were assembled for observatory use and then equipment for field recording was constructed (Section III).

With the inauguration of the Lamont Geological Observatory, all seismological station recording was transferred there, and the modified Bosch-Omori horizontal components described in Section IV were put into operation. A vertical component seismometer was constructed which matched the frequency response of the horizontals (Section IV). A good deal of accessory instrumentation work was required relative to the installation of a fully operating seismograph vault at the Lamont Observatory. A full description of the vault will be furnished in another report.

A low frequency mechanical oscillator was built at the Geophysics Laboratory at Columbia University for use as a laboratory source of low frequency electrical power. This is described in Section V.

The first installation of instruments completed under the program was made on 15 May 1948. A vertical component field seismometer was installed at Columbia University, and this, together with the station amplifier, a Brush penmotor and a drum recorder constituted the first seismograph assembly. In April 1949 this unit was moved to the Lamont Geological Observatory, where it is operating at present in modified form. The records obtained from this seismograph were used extensively in a microseism study made by W. L. Donn[1]. At present this seismograph uses galvanometric recording and provides high speed short period records for the Observatory.

During the summer of 1948 the field seismometers were used with the field amplifying and recording gear to obtain seismic refraction data off Point Judith, Rhode Island. Two boats, working offshore in connection with other projects of the Geophysics Laboratory provided the explosions. A similar project was undertaken during the summer of 1949 in the Gulf of Maine[2]. During

the summer of 1950 a land seismic refraction project was undertaken with the cooperation of the National Lead Company mine at Tahawus, New York.

Also during the summer of 1950, two vertical component seismographs were installed at Columbia University's Geophysical Field Station in Bermuda and were used, together with amplifying and recording equipment supplied by cooperating projects of the station, to obtain seismic refraction data and data on propagation of short period waves in the ocean off the shores of Bermuda. The research vessels ATLANTIS and CARYN supplied the explosions.

At present a third field seismometer is being set up in Bermuda to make a tri-partite installation with a base line of about 3 miles for the study of microseisms. A larger vertical component seismometer, of the type described in Section IV, was also installed at Fort George, Bermuda. This is intended to provide a vertical component for the pair of Milne-Shaw horizontal component seismographs now operating at Fort George under the direction of the U. S. Coast and Geodetic Survey.

The modified Bosch-Omori seismographs and the matching vertical component (Section IV) were installed at the Lamont Geological Observatory in April 1949.

A penmotor, described in Section II, was built and installed in a recording unit during the summer of 1949. At present, a unit mounting 3 penmotors is being installed to furnish 3 components of visibly recorded seismograms on standard-sized paper every 24 hours.

The instrumentation program described here has provided:

a) A three-component long-period seismograph at the Lamont Geological Observatory

b) A long-period vertical-component seismograph to complete a 3-component seismograph with the Milne-Shaw instruments at Fort George, Bermuda.

c) Three variable-period vertical-component seismometers for a tri-partite microseism station at Bermuda.

d) One variable-period vertical-component seismometer to provide short-period, high-speed records at the Lamont Observatory.

e) Five vertical-component and 3 horizontal-component field seismometers together with amplifying and recording gear for field seismic work.

f) A 3-component penmotor on a single drum for visible recording of 3 components.

g) An amplifier and recording drum for visible recording station seismographs.

h) A mechanical low-frequency oscillator for a laboratory source of low-frequency power.

In addition, design and construction work has proceeded on several other projects:

a) A frequency analyzing seismograph for recording of microseisms.

b) A shaking table for calibration of seismic pickups.

c) A linear strain seismograph.

d) Accessory instrumentation work relative to the improvement and expansion of seismological recording facilities at the Lamont Geological Observatory.

These projects will be briefly described under Current Instrument Projects. A fuller description will be furnished in other reports.

ACKNOWLEDGMENTS

Professor Maurice Ewing of Columbia University was the sponsor of the instrumentation program and extended invaluable advice during the design, development, and research incidental to the program.

Mr. Angelo Ludas of the Geophysics Laboratory, Columbia University, extended valuable technical advice in the design and construction of many instruments, and Mr. Harold Smith of the Lamont Observatory was very helpful in the installation of equipment in the seismograph vault.

G. R. Hamilton, M. Landisman, and H. A. Stark of the Columbia University Geophysical Field Station, Bermuda, were of great assistance in the installation of instruments. Especially valuable assistance and cooperation were furnished by A. J. Moulder of the Signal Station, Fort George, Bermuda.

Appreciation is extended to the many members of the Geophysical Laboratory who offered their cooperation in the field application of the seismic recording apparatus.

Assistance in the preparation of the various diagrams, graphs, and photographs was furnished by Mrs. Marie Flanagan and Mr. John Ewing.

SECTION I

FIELD SEISMOMETER

A vertical component field seismometer with great versatility of application was required as a first step in the instrumentation program to provide equipment for obtaining data in seismological investigations. The specifications included:

1) Ruggedness, compactness and light weight for field work.

2) High sensitivity.

3) Variable period to cover the range of frequencies of explosion sounds, microseisms and earthquakes. The vertical component seismometer described below was designed by B. Luskin and 10 of these instruments have been built at the Geophysics Laboratory of Columbia University by Henry Peckert.

The seismometer consists of a horizontal pendulum rotating about an axis determined by .002" thick crossed steel strips and suspended from a helical spring whose upper support may be varied in position over a wide range. All the structural parts are made of 24 ST aluminum. The chief part of the pendulum mass is contained in a coil which is enclosed by a magnet assembly firmly attached to the seismometer base plate. A hinged aluminum cover provides a rain-and-wind-tight housing for the instrument as well as affording mechanical protection.

In order to cover the frequency range specified, the pendulum was designed to be suspended by a spring with zero-length characteristics. The springs were purchased from John Chatillon, Inc., and were made according to design specifications. With this suspension, an infinite free period is theoretically attainable by proper adjustment of the relative position of the upper spring

support with respect to the axis of rotation. The range of periods, however, is limited practically by the low ratio of pendulum mass to friction and hence a maximum free period of 6 seconds is obtainable before the pendulum becomes unstable. By adjusting the upper support position of the zero-length spring, a range of free periods from 1 second to 6 seconds is obtainable, which is suitable for microseism and teleseism recording. For recording explosion frequencies, an ordinary steel helical spring, wound on a lathe, is used in place of the zero-length spring. The total range of periods obtainable then is 1/5 second to 6 seconds.

The electromagnetic assembly, consisting of the coil on the pendulum and the stationary magnet, was designed for high sensitivity and high impedance in order to connect the coil directly to the grid of an amplifier tube. The coil is wound with 50,000 turns of #46 B & S gauge wire and has a resistance of 80,000 ohms. It was found necessary to build a special machine, capable of handling such high gauge wire (.00157" diam.) to wind the coils. The magnet assembly consists of a cylindrical Alnico V permanent magnet and suitable pole-pieces to obtain a radial field of approximately 1500 gauss. The electrodynamic constant of the seismometer is 21×10^9 in emu units or 210 volts per radian per second in practical units. A 2-megohm resistor in shunt with the coil provides slightly less than critical damping.

A simple clamp positions the pendulum for assembly of the hinge strips and thereafter serves as protection for the pendulum during transport. The leveling screws are adjustable from outside the case and are made of brass with inserted stainless steel points. The entire instrument measures 13" x 15" x 6½" overall

and weighs 25 pounds.

A typical calibration curve of the instrument used with an electronic amplifier for station use is shown in Figure 1a (Electronic) and a photograph in Figure 2. The voltage output is given as a function of amplitude of earth motion in Figure 1b.

A horizontal component seismometer of the inverted pendulum type was also designed for field use. This instrument is tuned to about 3 cycles and utilizes the same electromagnetic assembly as the vertical component instrument. Three of this type have been built by Henry Peckert at the Geophysics Laboratory of Columbia University. These instruments match the vertical components in frequency response fairly closely. They measure 12½" x 10" x 6½" overall and weigh 25 pounds. A photograph of the horizontal component field seismometer is shown in Figure 3.

SECTION II

STATION AMPLIFYING AND RECORDING GEAR

For about one year, a short-period seismograph covering the range 1/3 to 1/10 seconds has been in operation at the Lamont Observatory at Palisades, New York. This unit uses a vertical component seismometer described in Section I, with free period set, at various times, between 1/3 and 1 second. The seismometer is coupled to a relatively insensitive and rugged Rubicon Type L galvanometer by means of a two-stage amplifier. The function of the electronic unit is primarily to couple the high impedance seismometer coil to the low impedance galvanometer without introducing the reaction of the galvanometer coil in the motion of the pendulum, a factor which limits the magnification of electromagnetic seismographs. This provides a short-period seismograph of high magnification without requiring high sensitivity galvanometers with low moment of inertia movements. The electronic units are extremely simple, utilizing geophysical output transformers having excellent low-frequency characteristics. This seismograph has been found especially useful for recording explosions, quarry blasts, near earthquakes, and certain high frequency phases of distant earthquakes.

Several systems for providing direct recording seismographs have been described in the literature[3,4,5,6]. Most of these make use of a galvanometer - photoelectric cell arrangement to couple the seismometer to an amplifier.

The direct recording seismograph operating in Palisades uses a special electromagnetic transducer (described in Section I) designed to give the seismometers large electrodynamic constants.

This enables direct coupling of the high impedance coil to the first stage of an amplifier. Electronic amplification of only several hundred is sufficient to operate at the limit set by normal microseismic activity, permitting the use of a rather simple high-fidelity amplifier having excellent stability and wide dynamic range (70 volts peak to peak output across a 1000-ohm load). The amplifier in operation at present, designed by M. K. Asdal, has flat response from 1-20 seconds, with possibility of extension of this range at either end. A circuit diagram is shown in Figure 4. An advantageous feature of the amplifier is the use of a large degree of inverse feedback to obtain relative independence from variations in the values of the components in voltage supply, and to improve linearity. Another feature is the low value of the output impedance (about 50 ohms) which makes for convenient damping of the pen motor.

The recorder (Figure 5) constructed by L. C. Eichner Co. of Clifton, New Jersey, consists of a triple drum unit mounting three ink-recording galvanometers of conventional design*. A 24-hour record from each component is made on 11½ x 36" paper at speeds of either 30 mm/min or 60 mm/min. Simplicity and low cost were the guiding principles in the design of the recording unit. Thus the drum is made of a strong plastic material and translation of the drum is obtained by mounting the drum shaft on two pairs of inclined wheels. A circular tube filled with shot is mounted on the drum to eliminate backlash in the gears and synchronous motor.

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* Glass pens were kindly supplied by Professor Hugo Benioff.

The direct recording seismograph has been in operation with several minor modifications for over two years, using both short and long period seismometers. The frequency response of the unit was sufficiently broad to record most of the earthquake phases except the longest surface waves. Typical magnification curves using short and long period seismometers are shown in Figure 1a.

A four-component unit is now being installed using a short period vertical seismometer (to about 1/2 second) and longer period N-S, E-W, and Z seismometers (to about 12 seconds). The seismometers are described in Sections I and IV.

SECTION III

FIELD AMPLIFYING AND RECORDING GEAR

The seismic field equipment for each recording station consists of one vertical and one horizontal seismometer, the design and characteristics of which are described in Section I; a set of two low-frequency amplifiers driving a two-channel Brush recorder; a break-circuit chronometer; a modified short wave receiver; a power supply consisting of a 6-volt storage battery and vibrator; and accessory equipment. Each of these components is described in the subsequent paragraphs.

Illustrations

Amplifier and Recorder

The amplifier was modified by S. Katz from a design originally furnished by the Department of Terrestrial Magnetism, Carnegie Institution of Washington. It consists of four resistance-capacity coupled stages of voltage amplification, using 6AK5 pentodes, and a final power stage, using a 6AQ5, triode connected. The diagram for this circuit appears in Figure 6. Provision is made for applying a test signal of from 10 to 5000 microvolts to the input, for controlling the upper frequency cut-off response, for accepting a large signal requiring only one stage of amplification, and for controlling the d-c level of the output voltage. The 1N34A diodes protect the recording element and the writing pens from excessively large signals.

The frequency response of the amplifier is shown in Figure 7. The lower half-power point occurs at 1.35 cps; while the upper half-power point is as shown, a function of the setting of the condenser, shunting the plate resistance of the third stage. The maximum usable gain of the amplifier is 105 db. Although available, it is usually not possible to use higher gain because of amplifier and battery supply noise. The amplifier output is linear for input signals not exceeding 1.6 millivolts.

The power stage is a cathode follower. The use of a negative plate supply voltage and the proper choice of circuit values makes it possible to keep the cathode voltage at ground for zero signal input and to operate the recording element with no direct current component.

The filament power is obtained from a 6-volt storage battery; while for the purpose of decoupling, two sets of hearing-aid batteries furnish the plate supply. The plate supply for the power stage is a separate set of "B" batteries.

The output of the amplifier is applied to a Brush penmotor, having an impedance of 1500 ohms, resistive, and a voltage sensitivity of 1.1 mm per volt. The amplified signal is written on a tape which moves at 5 mm or 25 mm per second depending upon the desired accuracy and availability of paper. The power required for the paper drive, 110 volts at 60 cps, is furnished by an a-c vibrator, from a 6-volt storage battery.

Chronometer, Radio, and Automatic Junction Box

One-second break-circuit chronometers provide a time scale, written by a third pen mounted on the Brush two-channel recorder. The time scales at the shot and the various receiving stations

are synchronized against WWV's one-second time marks, both the WWV and the chronometer signals being simultaneously recorded on the Brush tape during time checks, preceding and following the record.

The radios are slightly modified, battery operated, standard short-wave receivers. The plate load of the first audio stage consists of an L-C combination, parallel resonant at 1000 cps, and series resonant at 500 cps, thus favoring the 1000 cps, one-second ticks over the continuous tone and over any interference.

In order to operate as many as three receiving stations, as well as the shot station simultaneously, an automatic junction box was designed to turn all the various components on and off at pre-determined times. The junction box consists of a clock with a 3-inch face, two double-pole, double-throw relays and a small 30-volt battery. To the arms of the clock are attached small brushes, which make and break contact, closing and opening a relay at pre-set times. This junction box controls four separate circuits and was found to be extremely useful for the seismic work carried on at Tahawus, New York.

A circuit to trip a relay in synchronism with WWV's one-second signal was designed and constructed. It consists of a monostable multivibrator which is triggered by the WWV signals, and recovers in approximately one-half second, when it becomes ready once more for the next WWV signal. With good radio reception, the circuit has worked well over periods of several hours, even in the presence of some static. In the presence of severe fading, this system is, of course, useless. The diagram for this circuit appears in Figure 8. While this device was designed to replace a break-circuit chronometer, it was not widely used in the field and no reliable claims can be made for it.

SECTION IV

CONVERSION OF BOSCH-OMORI MECHANICAL SEISMOGRAPHS TO ELECTROMAGNETIC SEISMOGRAPHS

A pair of Bosch-Omori seismographs was converted into Galitzin type seismographs at the Lamont Geological Observatory. A vertical component was designed and built with matching response characteristics to complete a 3-component seismograph with a peak magnification of approximately 2500. The conversion of the Bosch-Omori instruments was made quite simply and at little expense. Since the details of the conversion may prove of interest to those observatories in possession of the Bosch-Omori instruments, a complete description of the instruments is presented.

Omori described the first model[7] and an improved model[8] of his horizontal component seismograph around 1900. The firm of J. and A. Bosch of Strasbourg made additional improvements[9]. The final form of the instrument used a mass of 100 kg., mechanical registration on smoked paper and had a magnification of 80-100.

The mechanical linkage system and recording apparatus were removed from the or iginal instrument. A 1" x 1" aluminum bar 50 cm long was screwed into the cylindrical mass and a coil and copper damping plate were attached to the aluminum bar. The damping magnet is a surplus U. S. Navy radar magnet with a 4000 gauss field. The seismograph magnet assembly is composed of a cylindrical Alnico V magnet and appropriate pole pieces to form a radial field of approximately 1500 gauss. The coil is wound on a plastic form with #40 wire and has 10,000 turns. A mirror was mounted on the end of the aluminum bar and a plexiglass case constructed to cover the lower half of the instrument.

The recording is done electromagnetically and optically in the usual manner with a sensitive 14-second Type 2500F Leeds & Northrup galvanometer and a standard recording drum.

A photograph of the instruments is shown in Figure 10. The calibration curves are shown in Figure 11.

The vertical component instrument was designed by B. Luskin and built in the Geophysical Laboratory at Columbia University. It consists of a horizontal boom of 4.5 kg mass suspended by a spring with zero-length characteristics. The coil form and magnet assembly are the same as on the horizontal components, but the coil is wound with 25,000 turns and gives the vertical component seismometer a much higher electrodynamic constant. The damping is accomplished by placing a suitable resistance in shunt with the seismometer coil. An identical galvanometer to those of the horizontal components is used for recording. As can be seen from the magnification curves, the vertical component matches the modified Bosch-Omori components quite satisfactorily.

The modified Bosch-Omori components may be used to drive several galvanometers without great loss of magnification because their large mass reduces the coupling effect of the galvanometers. Following Schmerwitz[10], we may describe the reaction of the galvanometer coil in the motion of the pendulum by means of the coupling factor σ

where

$$\sigma = \frac{1}{2\sqrt{k k_1 K K_1}} \frac{S G g}{Q^2}$$

where k and k_1 are the damping coefficients for the seismometer and galvanometer respectively, K and K_1, their moments of inertia,

G and g their electrodynamic constants, S the value of the shunting resistance and Q^2 the sum of the products, taken two at a time, of seismometer coil resistance, galvanometer coil resistance and shunt resistance.

For an ordinary Galitzin seismograph, σ is about 0.2[11]. Wenner and McComb[12] give $\sigma = 0.557$ for a Wilip-Galitzin seismograph. The value of σ for the modified Bosch-Omori seismographs is .014 and for the vertical component, $\sigma = .08$.

Due to a shortage of recording drums, only the north-south component now has a second coil which drives an electronic amplifier and a pen-and-ink recorder. A three-component pen-and-ink recorder is now being installed.

It is intended to record the horizontal components with short period galvanometers in the future.

SECTION V

A MECHANICAL LOW FREQUENCY OSCILLATOR

A mechanical low frequency oscillator has been built at the Geophysics Laboratory of Columbia University which will give a sine wave output of magnitudes up to 150 volts peak independent of frequency from 1/2 cps to 1/300 cps. A stable oscillator for this frequency range is very difficult to build electronically. Recent commercial electronic models present great improvements over the early ones but are quite expensive. The mechanical oscillator has the advantages of great frequency and amplitude stability for the frequency range it covers, and can be built in the laboratory quite simply.

The mechanical oscillator described here was built as a laboratory instrument with two chief needs in mind: (1) a source of low frequency voltage for calibration of seismograph amplifiers; (2) a source of low frequency voltage for driving a shaking table electromagnetically for calibration of seismometer.

The principle on which the oscillator design is based is well known. If a three-phase voltage is impressed on a three-phase winding, the resultant flux vector will rotate with a synchronous speed corresponding to the frequency of the voltage and number of poles of the winding. The quantitative relation is:

$$N_s = \frac{120\ f}{p} \qquad (1)$$

where N_s = synchronous speed

f = frequency

p = number of poles.

If the three-phase winding is on the stator of a rotating machine and the rotor winding (single phase) is turned by a motor at speed N, then the effective flux cut by the rotor is

$$\varphi = \varphi_m \sin (N_s \pm N)t \qquad (2)$$

where φ_m = the stator flux

t = time

and the plus or minus sign is taken depending upon whether the rotor is turned oppositely or with the direction of rotation of the stator field.

The voltage induced in the rotor will then be

$$e_r = K\varphi_m(N_s \pm N) \cos(N_s \pm N)t \qquad (3)$$

where K is some constant depending on the properties of the rotor winding.

If we impress a three-phase voltage on the three-phase stator windings of the two generators, turn their rotors in opposite electrical sense, and connect the rotor windings in series, the output voltage will be

$$e_o = K\varphi_m\left[(N_s-N) \cos(N_s-N)t + (N_s+N) \cos(N_s+N)t\right] \qquad (4)$$

which can be changed by trigonometric substitution to read

$$e_o = K\varphi_m\left[N_s \cos N_s t \cos Nt + N \sin N_s t \sin Nt\right] \qquad (5)$$

Now let us take N_s as the synchronous speed corresponding to 60 cps frequency for a given machine. Then $N_s = 60$ C where $C = 120/p$. Let us also consider that the highest frequency of interest is 1/2 cps. Then $N = C/2$ and $N_s/N = 120$. Therefore, the second term in the bracket of (5) can be neglected with negligible error compared to the first term at the highest frequency of interest. Obviously the error becomes smaller the lower the frequency.

The output voltage of the rotors is then

$$e_o = (K\phi m \; N_s \cos NT) \cos N_s t \qquad (6)$$

This voltage is a sinusoidal wave of frequency corresponding to N_s (60 cycles), whose amplitude varies sinusoidally with the frequency corresponding to the speed of rotation of the rotors. This is, of course, a 60-cycle modulated wave. It remains only to detect this voltage; that is, take the rectified output across an appropriate resistor-condenser circuit, to obtain the envelope of the wave which is the desired low frequency output. Theoretically, then, there is no lower limit to the frequency output of this system and the amplitude of the output is independent of the frequency.

Practically, of course, there are limitations. The amplitude will depend upon the stability of the 3-phase line voltage both as regards amplitude and frequency since the latter control the value of ϕm and N_s. Furthermore, the stability of the modulating frequency will depend on the speed regulation of the driving motor. However, these problems are simpler than the corresponding problems for electronic oscillators in the same frequency range.

A schematic diagram of the mechanical oscillator is shown in Figure 12, and a photograph in Figure 13. The generators are small synchro-generators, and the motor is a single-phase AC motor. These parts are all available as war surplus products and quite inexpensive.

The method of controlling the speed of the driving motor is to drop the line voltage across it by means of a General Radio Variac auto-transformer. The Variac control supplies continuous variation of speed between steps of gear-ratio changes. A stable continuous spectrum is available with this control from 1/2 cps to 1/300 cps.

If a voltage regulator transformer is used in conjunction with the oscillator, the output becomes practically independent of line voltage amplitude variations. Line frequency variations are less easily overcome but these are not serious on the ordinary circuit.

The use of this oscillator is somewhat restricted due to the requirement of 110 volts 3-phase electricity for its operation. Three-phase voltage is not always available in a laboratory and very rarely at 110 volts. At the Geophysics Laboratory, it was found necessary to lead in 220 volts 3-phase from the nearby machine-shop and use 100 watt lamps as dropping loads.

The metering of the oscillator output may be done by timing the shaft rotations for frequency and using a voltmeter for amplitude. It has been found far simpler to switch the output to a penmotor recorder such as the Brush or Esterline-Angus recorders for metering purposes and thus obtaining both frequency and amplitude at once.

The high output voltage of the oscillator necessitates a volume control for metering purposes or for calibrating an amplifier. It is useful, however, without attenuation for driving power tubes which in turn may drive a shaking table electromagnetically for calibrating seismometers. The mechanical oscillator described here, then can perform a very useful purpose by providing a source of stable low-frequency sinusoidal voltage of high amplitude for calibration of seismological instruments.

CURRENT INSTRUMENT PROJECTS

At the present time, instrumentation projects in various stages of completion are going forward with the general purpose of expanding and improving the available facilities for obtaining seismological data. Two projects are concerned with providing new and highly specialized instruments to obtain data in support of theoretical investigations already reported[13]. Other projects are concerned with accessory instrumentation in support of the existing installation.

A frequency-scanning seismograph has been designed by B. Luskin and M. Ewing and is being constructed by the L. C. Eichner Instrument Co., Clifton, New Jersey. The seismometer is a vertical component whose free period may be varied from 1.5 to 20 seconds. Recording will be done electromagnetically and optically. The seismograph will be used as a frequency scanning device to cover the microseism range of periods. The scanning is done automatically by a motor which changes the relative positions of the upper spring support and the axis of rotation for recording periods determined by a program mechanism. Thus a spectrum analysis of the microseism frequency range is obtained automatically. It is also expected that this instrument will differentiate between storms over different depths of water and will be able to record more distant storms that heretofore possible because of its narrow band tuning.

A linear strain seismometer is under construction from plans kindly supplied by H. Benioff, its inventor[14]. The very long period response of this instrument is expected to be especially valuable in obtaining data for study of surface wave dispersion in the very long period range and the study of the deeper discontinuities.

A shaking table for the dynamic calibration of seismic transducer elements is under development under the direction of W. Beckmann. The table will be capable of calibrating pickups as large as the field seismometer described in Section I.

An independent and highly stable source of 60-cycle power derived from a tuning-fork oscillator is being developed by H. Owen of the Lamont Observatory to run the various recording drums. Improvements are also being made in the circuits which produce a Naval Observatory time check on the seismograms at two-hourly intervals.

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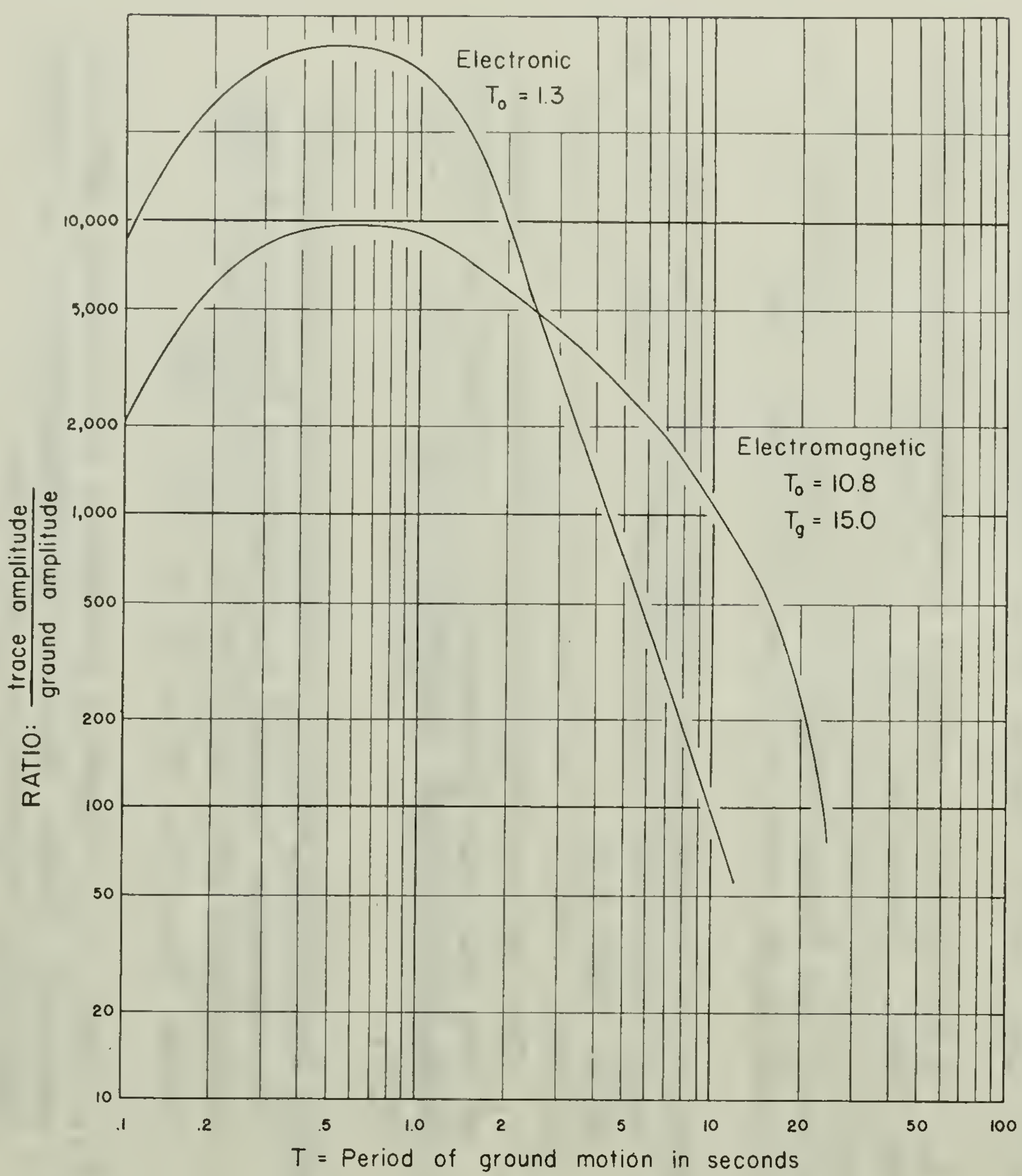


Figure 1a

Calibration Curves. Electronic curve refers to the field seismometer used in conjunction with an electronic amplifier and tuned to a free period of 1.3 seconds. Electromagnetic curve refers to the N-S component of the Modified Bosch-Omori Seismograph used with a similar amplifier.

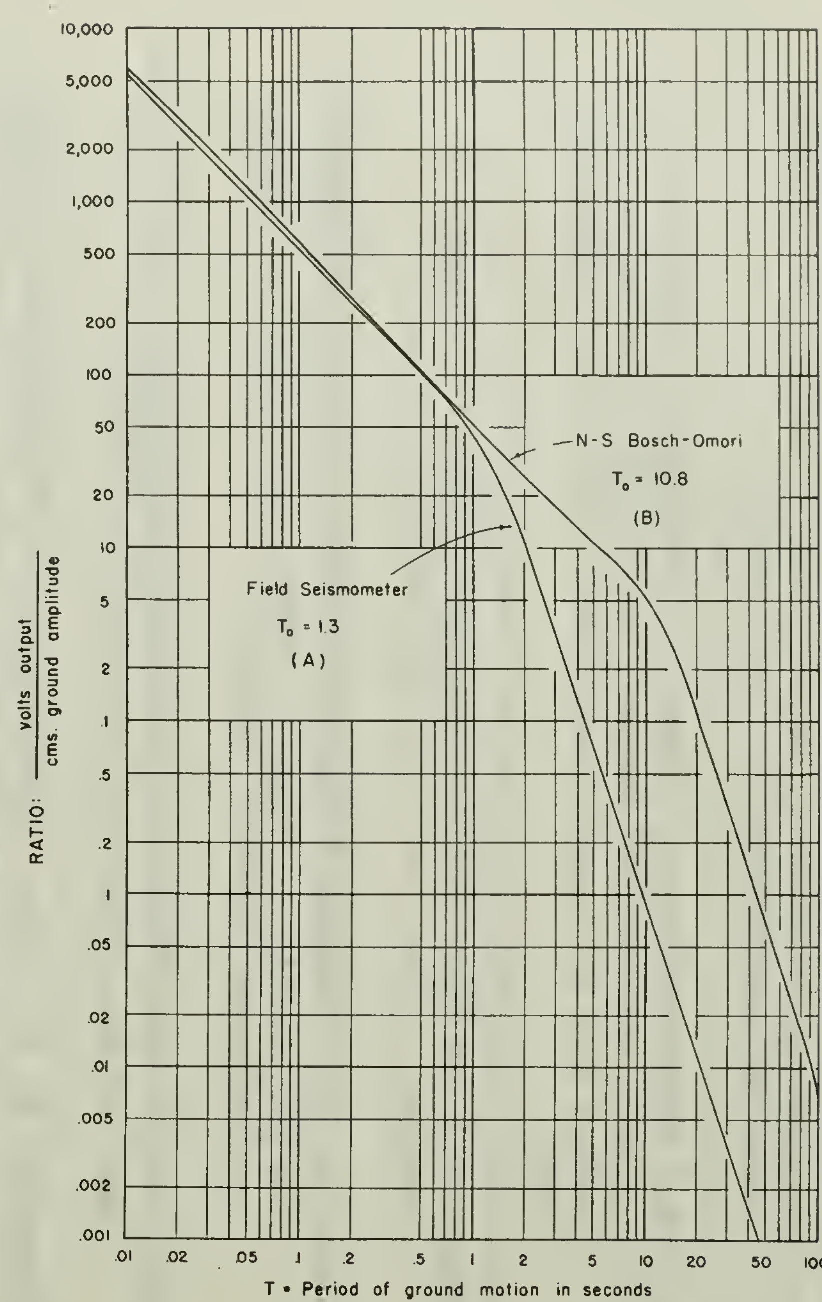


Figure 1b

Calibration Curves. (A) Vertical Component Field Seismometer
(B) N-S Modified Bosch-Omori Seismometer

Figure 2

Vertical Component Field Seismometer

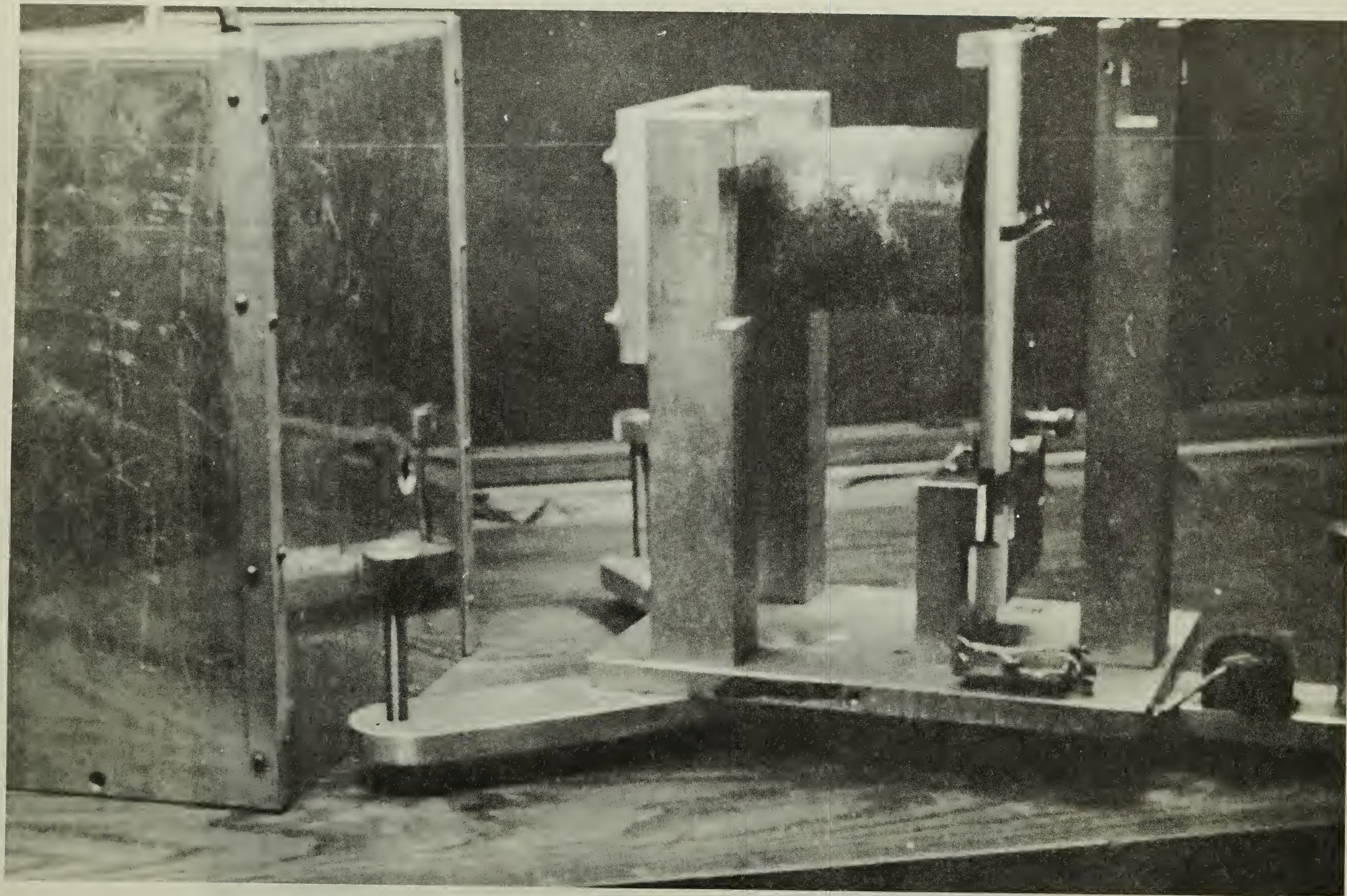


Figure 3

Horizontal Component Field Seismometer

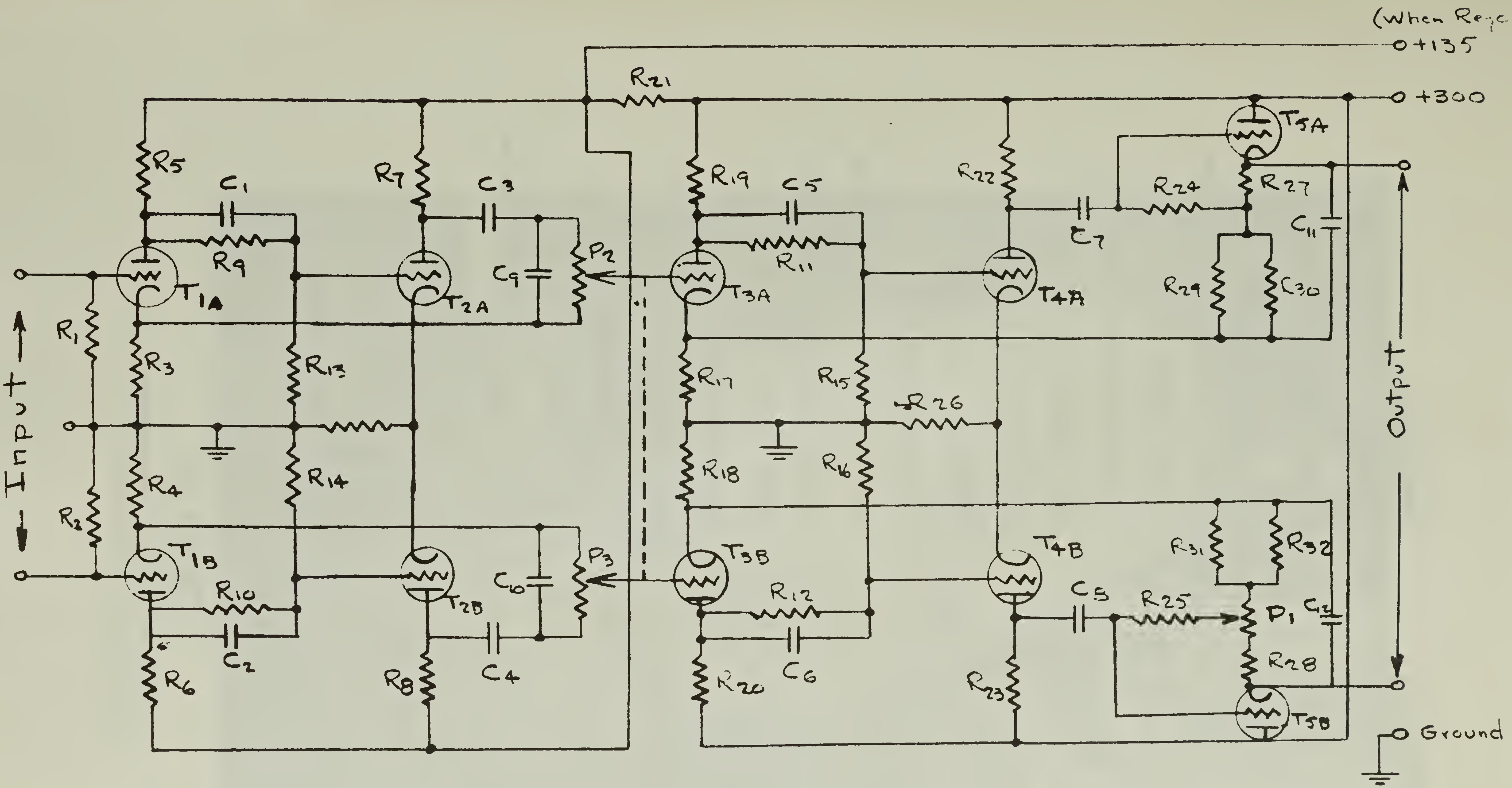


Figure 4 (a)

Circuit Diagram of Low Frequency Amplifier

Designation	Description
R_1, R_2	220K Wire Wound Resistance
R_3, R_4	5K Wire Wound Resistance
R_5, R_6, R_7, R_8	175K Wire Wound Resistance
R_9, R_{10}, R_{11}, R_{12}	10 meg. Composition Resistance
R_{13}, R_{14}, R_{15}, R_{16}	1 meg. Composition Resistance
R_{17}, R_{18}	31 ohm Wire Wound Resistance
R_{19}, R_{20}	470K Composition Resistance
R_{21}	165K Wire Wound Resistance
R_{22}, R_{23}, R_{24}, R_{25}	680K Composition Resistance
R_{26}	18K Composition Resistance
R_{27}	560 ohm Composition Resistance
R_{28}	470 ohm Composition Resistance
R_{29}, R_{30}, R_{31}, R_{32}	10K Wire Wound Resistance
R_{33}	20K Wire Wound Resistance
C_1 through C_8	1 mf. Condenser
C_9, C_{10}	0.05 mf. Condenser
C_{11}, C_{12}	6 mf. Condenser
P_1	200 ohm Wire Wound Potentiometer
P_2, P_3	470K Decade Potentiometer
T_1, T_2, T_3, T_4	6SL7 Vacuum Tubes
T_5	6SA7 Vacuum Tube

Figure 4 (b)

Table of Circuit Components

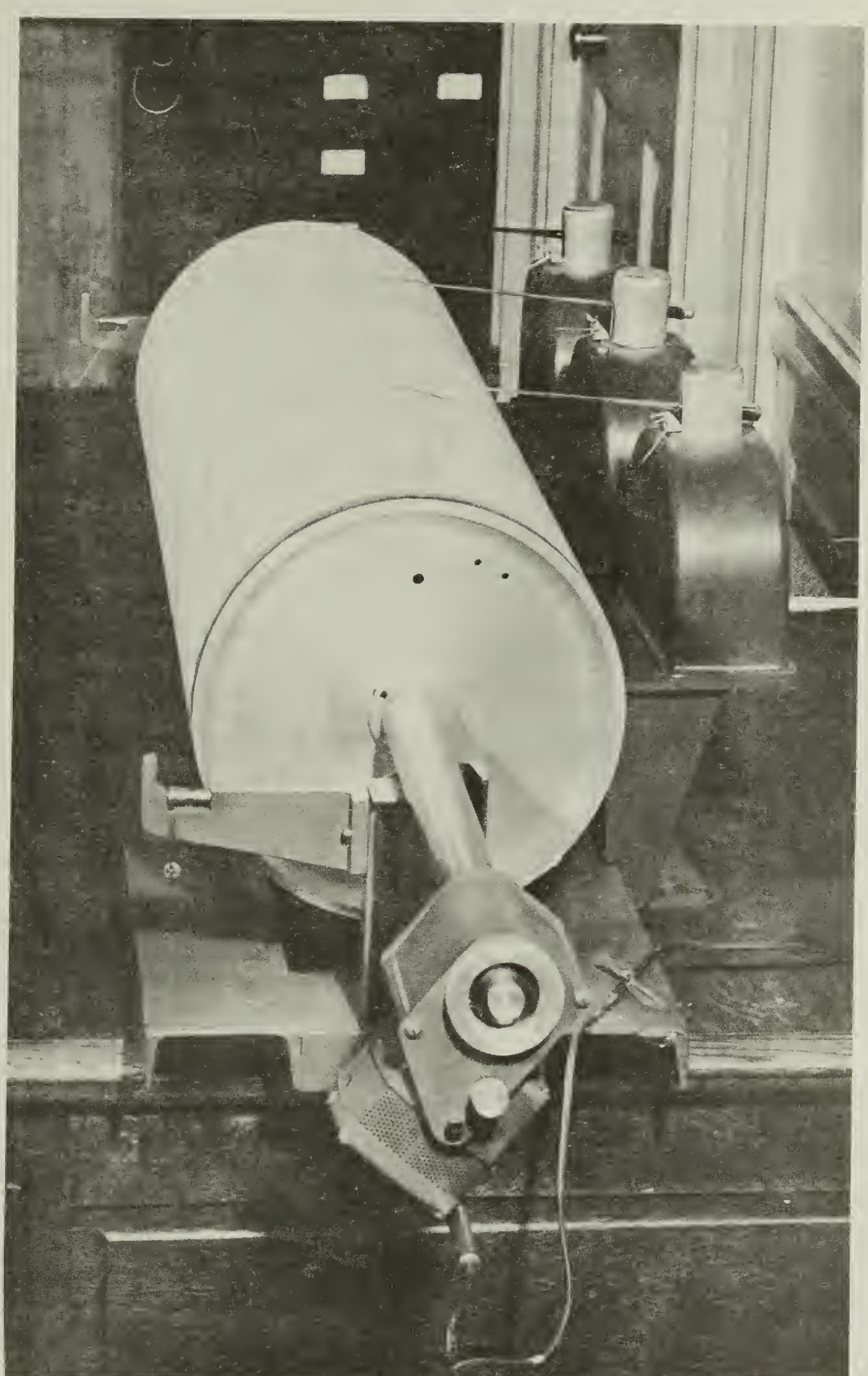


Figure 5

Three-pen Drum Recorder

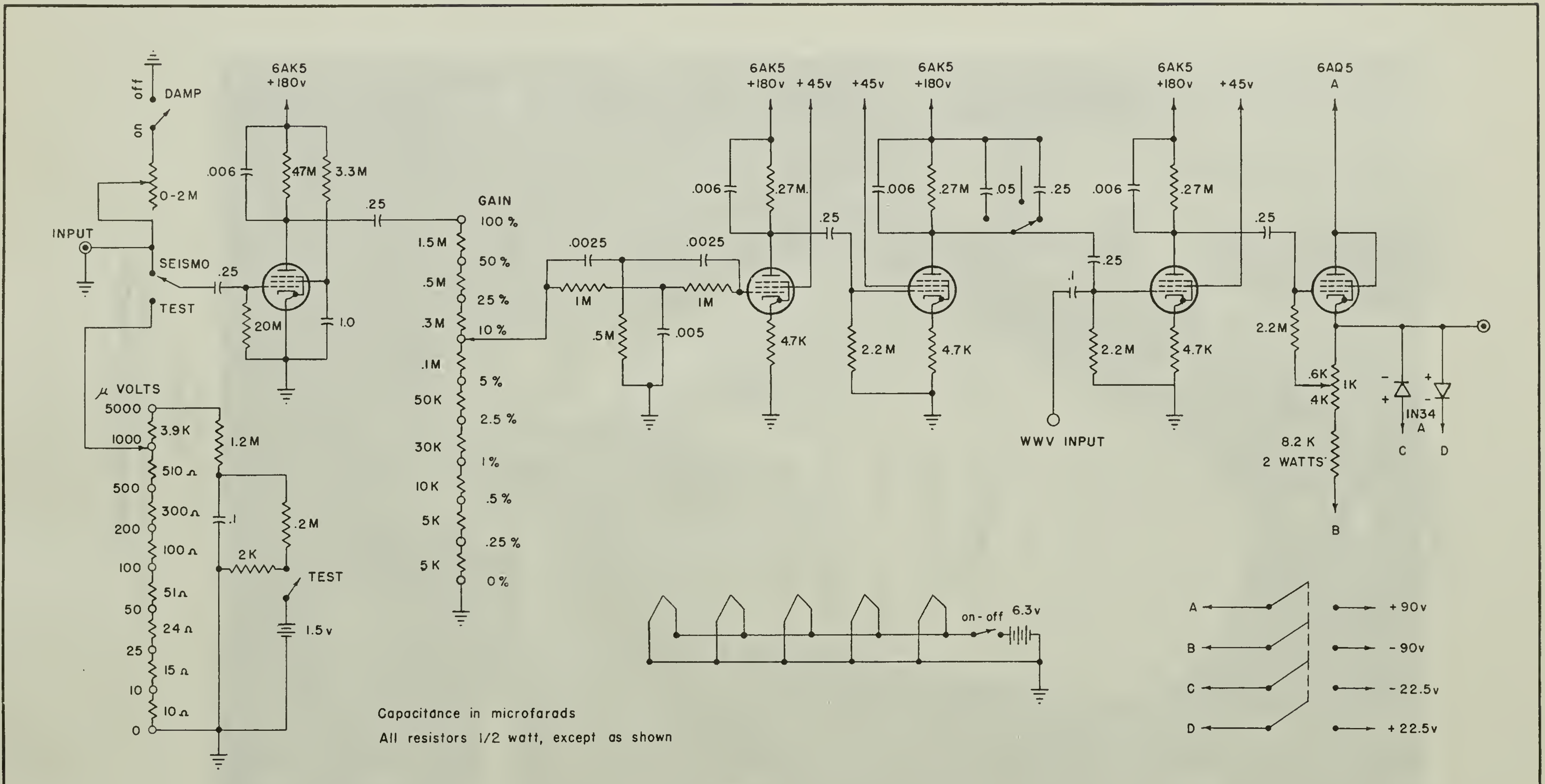


Figure 6

Circuit Diagram of Field Amplifier

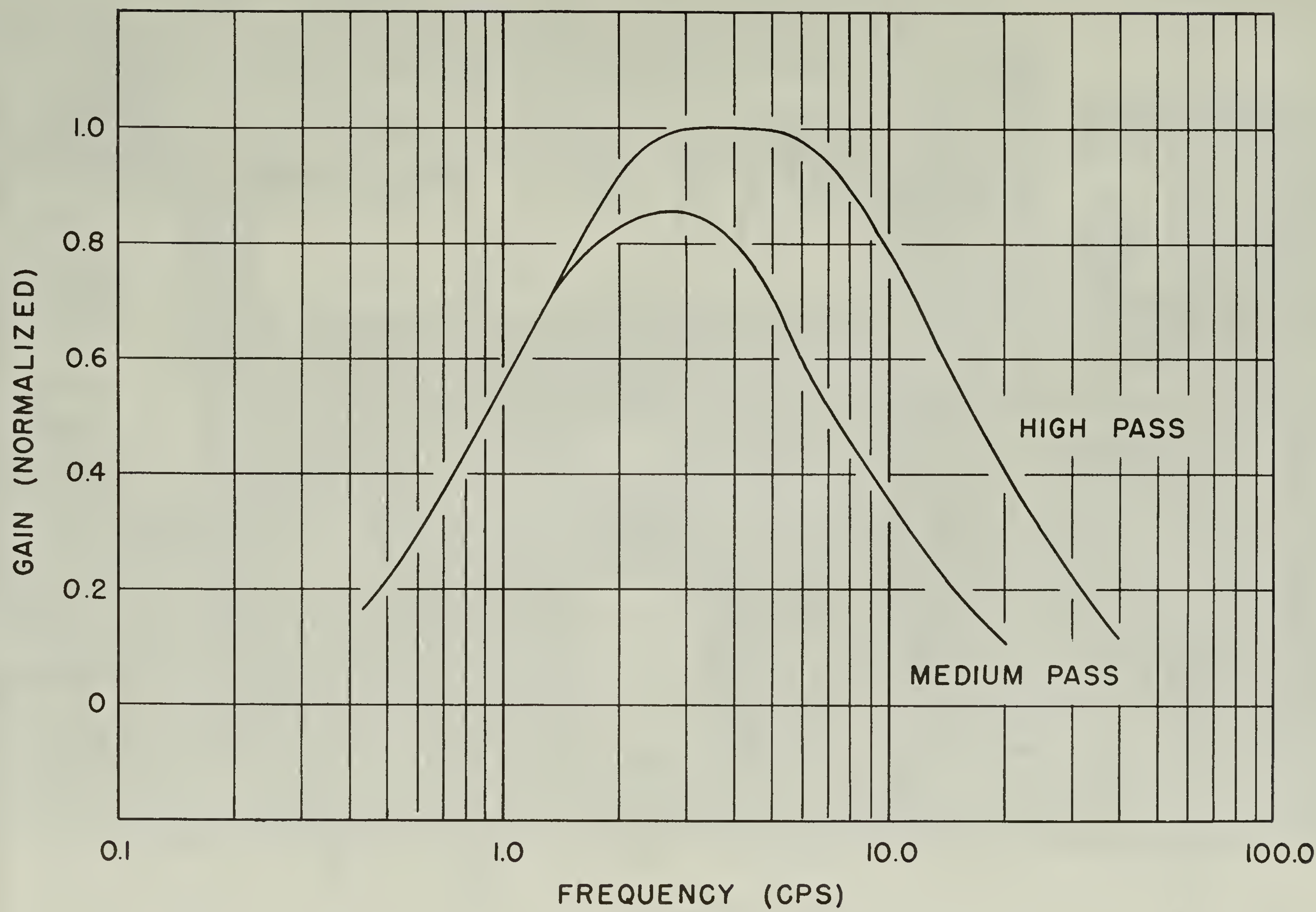
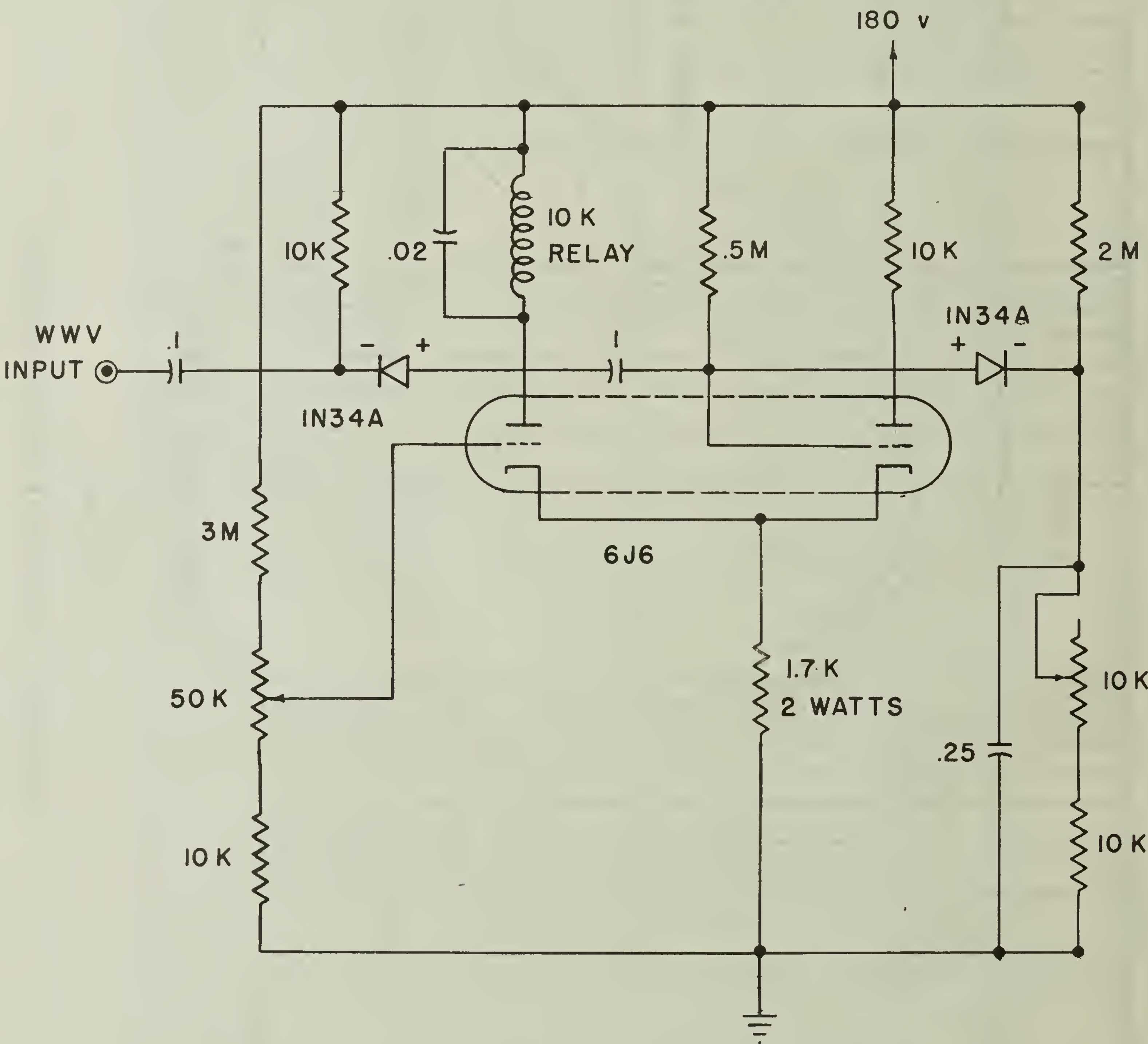


Figure 7

Frequency Response of Field Amplifier



Capacitance in microfarads

Resistance 1/2 watt; except as shown

Figure 8

WWV Ticker

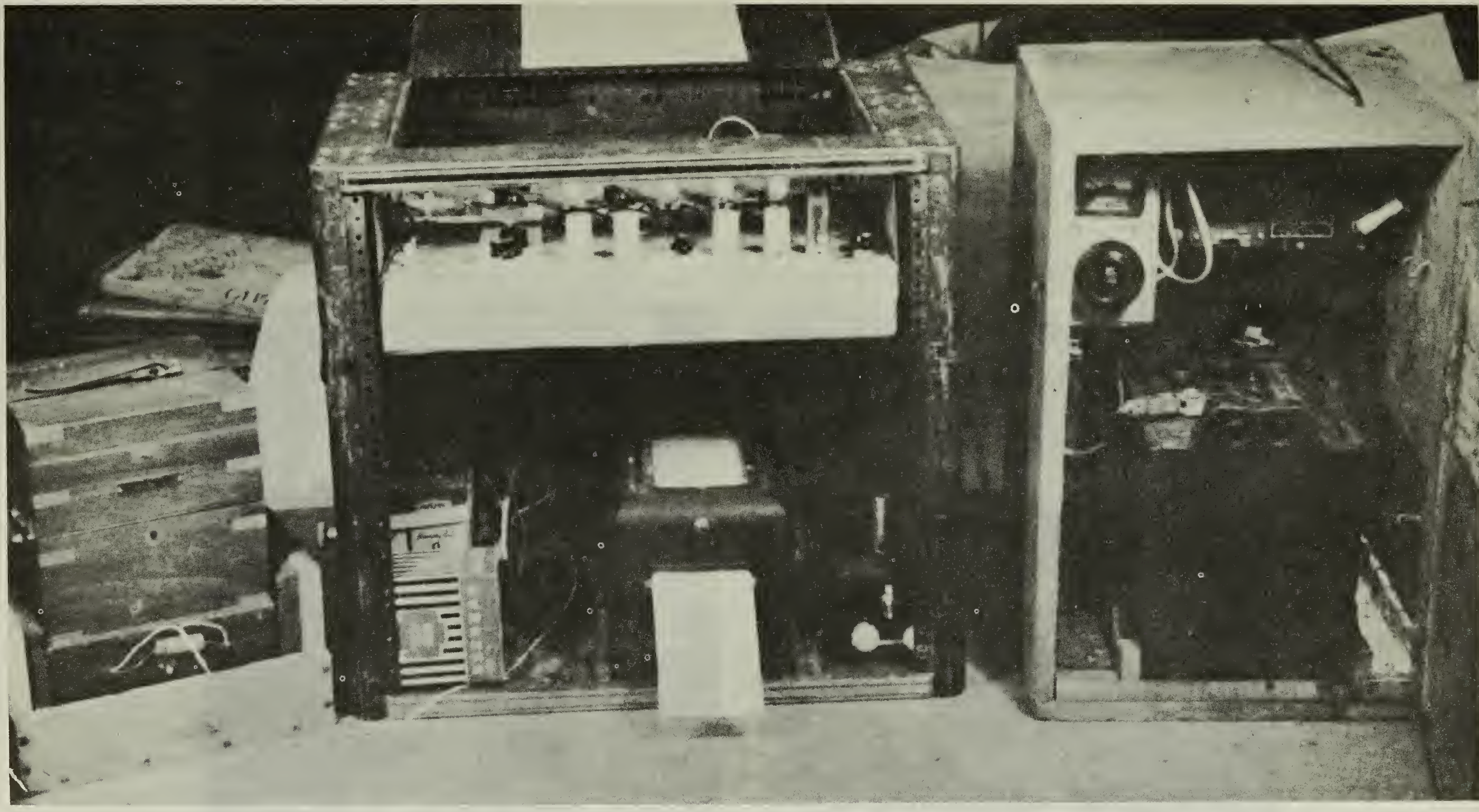


Figure 9

Field Setup

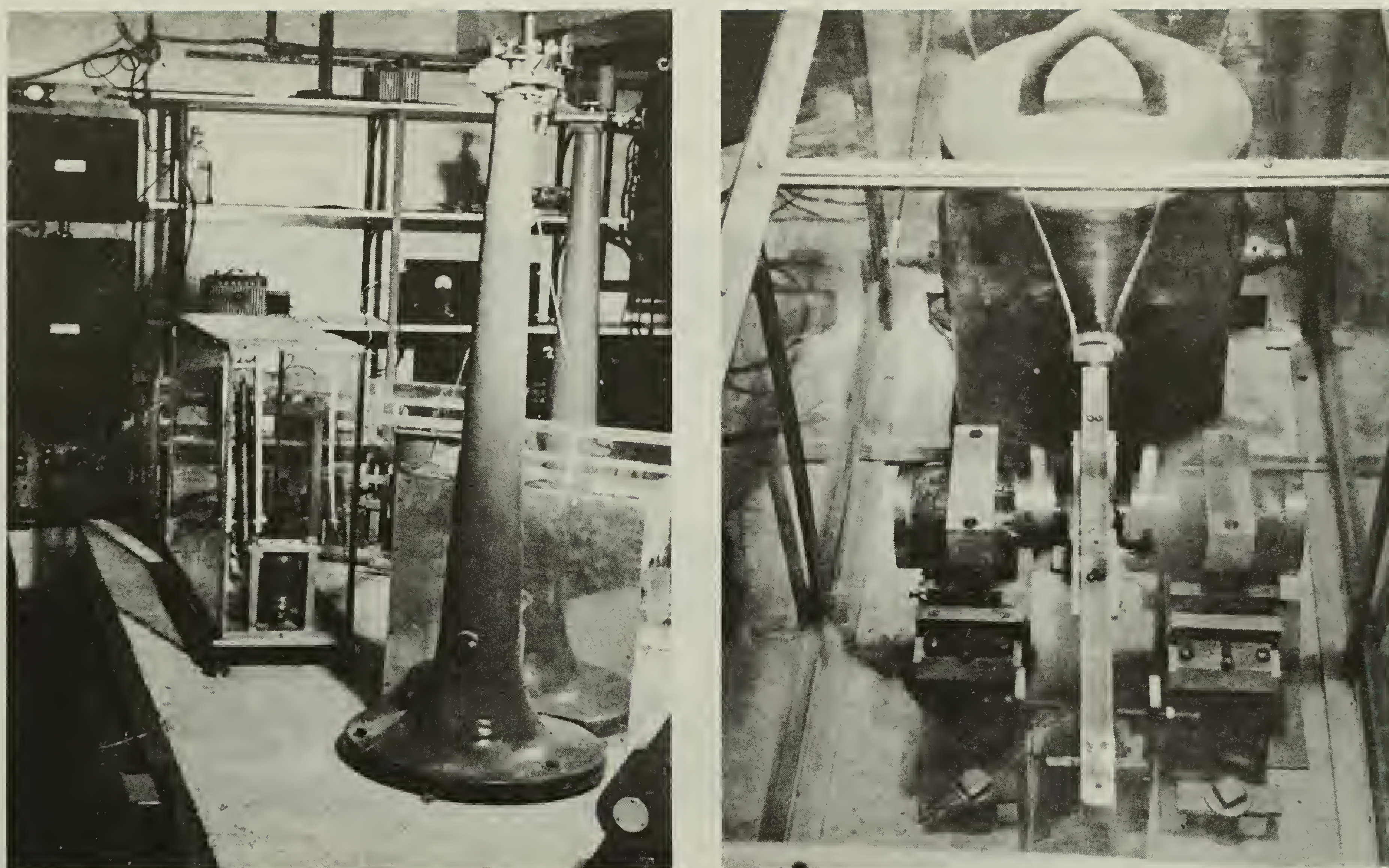
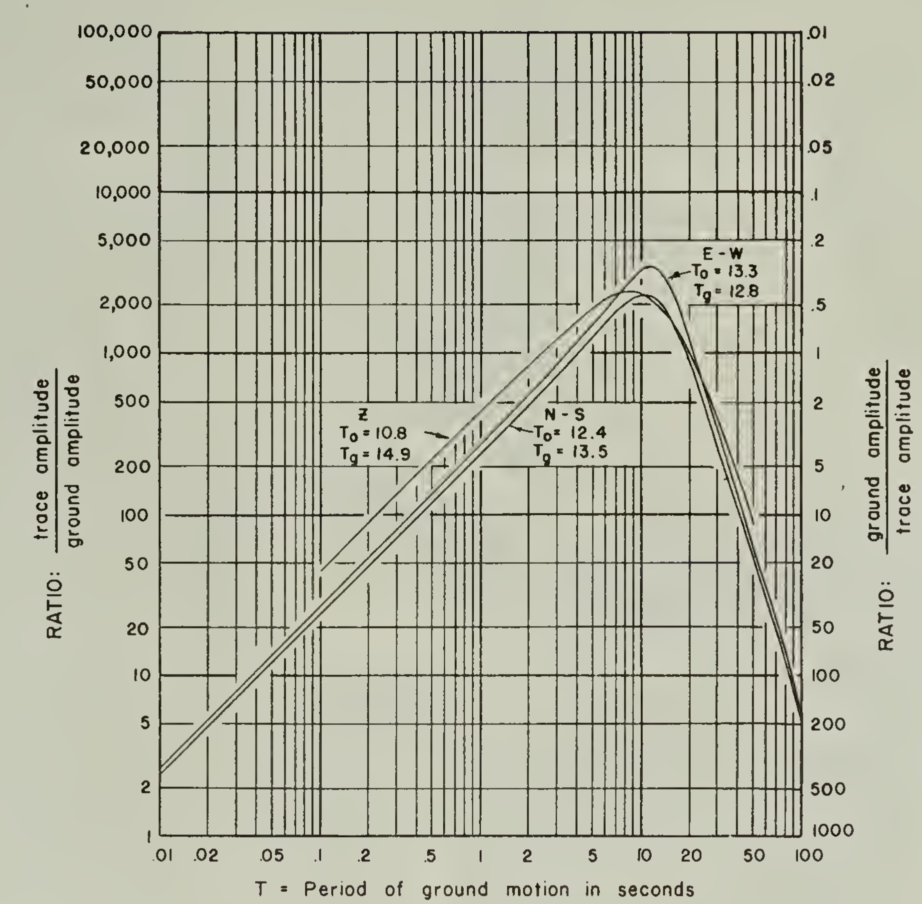


Figure 10

(a) Three-component electromagnetic seismograph including 2 modified Bosch-Omori horizontal components and a matching vertical component

(b) Electromagnetic assembly of modified Bosch-Omori seismometer



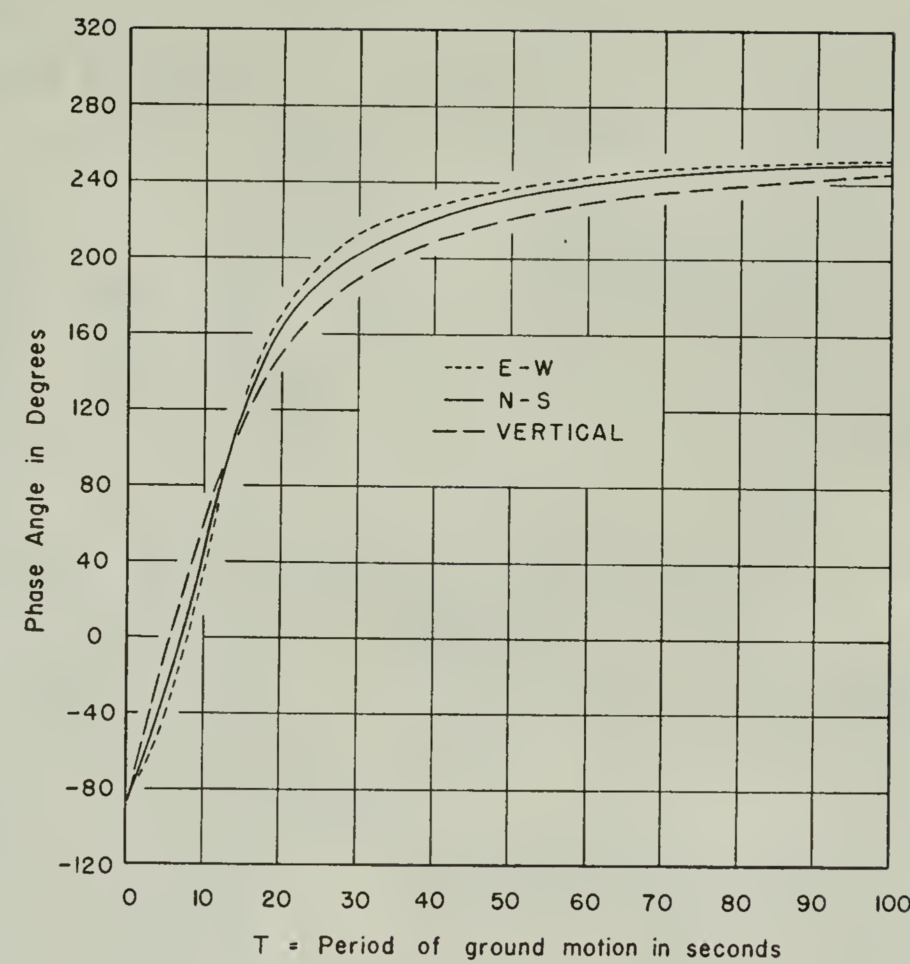


Figure 11

(a) Amplitude Response of Three-Component Electromagnetic Seismograph

(b) Phase Response of Three-Component Electromagnetic Seismograph

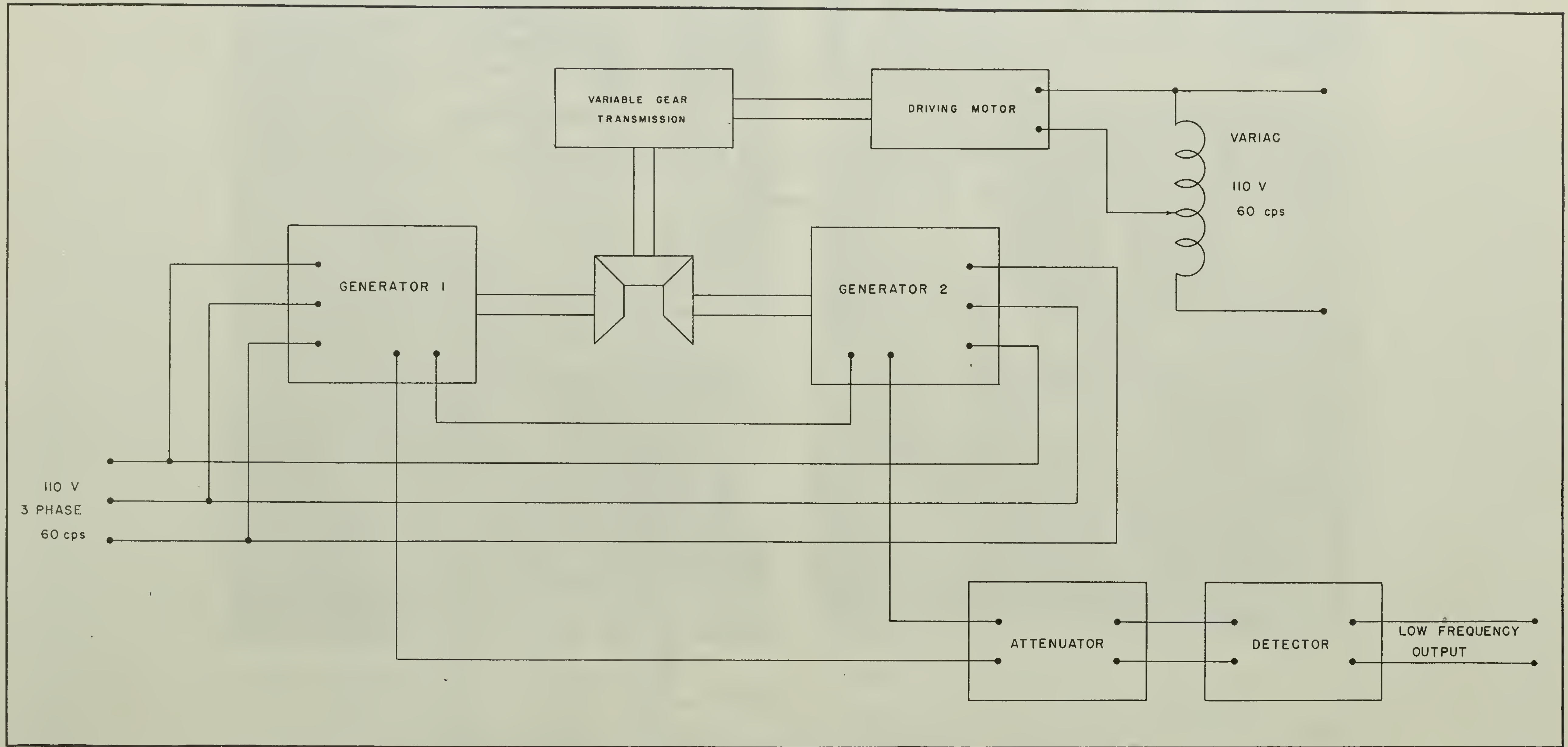


Figure 12

Schematic Diagram of Mechanical Low Frequency Oscillator

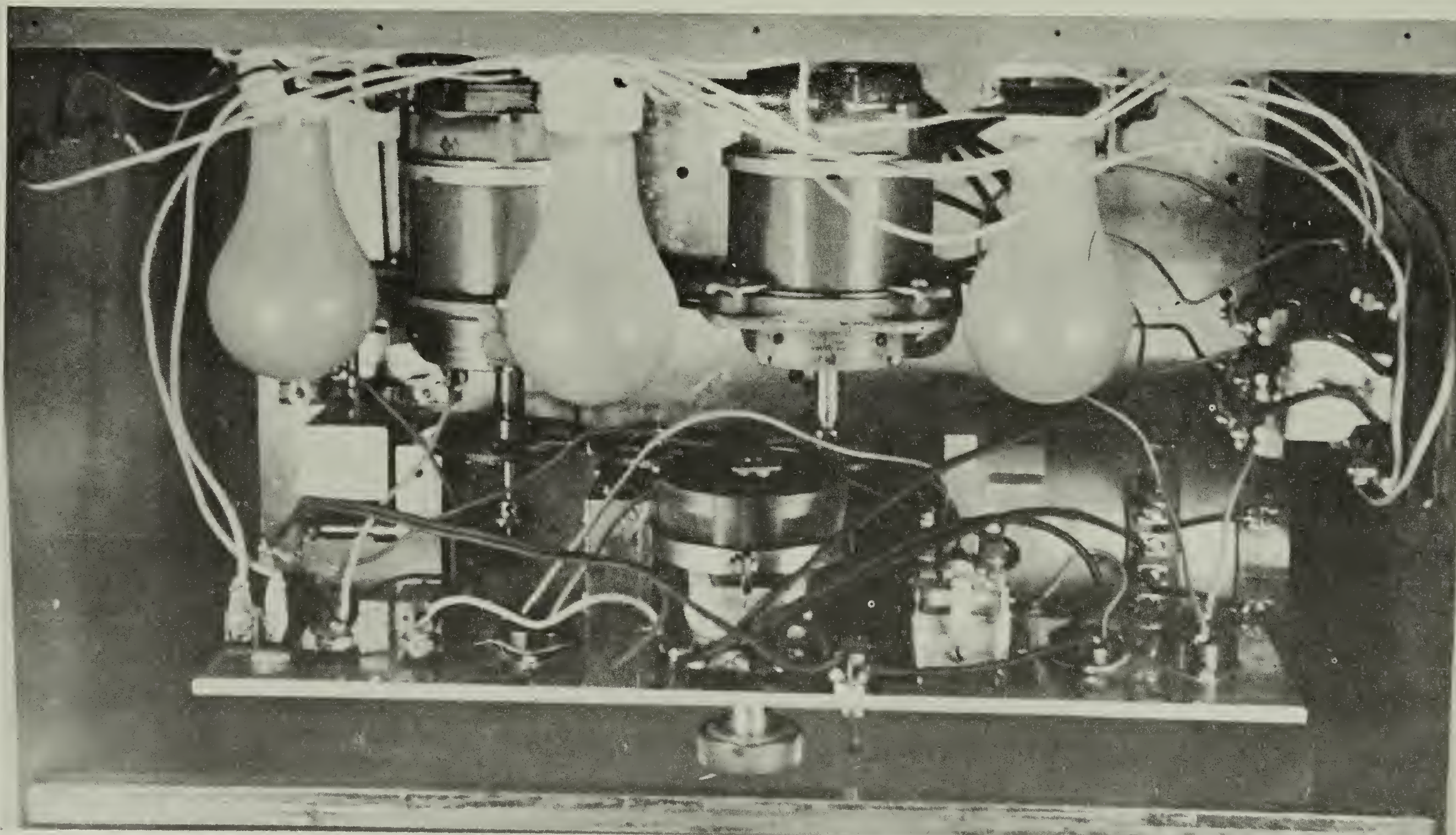


Figure 13

Photograph of Mechanical Low Frequency Oscillator